MOBILE DETECTION ASSESSMENT RESPONSE SYSTEM

DoD's Automated Security and Inventory Assessment Capability

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The Mobile Detection Assessment and Response System (MDARS) program is a joint Army-Navy effort to develop a robotic security and automated inventory assessment capability for use in Department of Defense (DoD) warehouses and storage sites. Near-term objectives are improved effectiveness and less risk to a smaller guard force, along with significant reduction in the intensive manpower requirements associated with accounting for critical and high-dollar assets.

The initial MDARS Interior implementation involves eight Cybermotion K2A Navmaster robots configured as remote security platforms [Laird, et al., 1993]. Two real platforms and two simulated platforms are currently operating in a government warehouse facility at Camp Elliott in San Diego, CA. The MDARS Exterior program extends the robotic security and inventory control concepts into the realm of semi-structured (i.e., improved roads, defined fence lines, and standardized storage layouts) outdoor environments such as storage yards, dock facilities, and airfields.

Background

The MDARS program is managed by the US Army Physical Security Equipment Management Office, Ft. Belvoir, VA, with the Naval Command Control and Ocean Surveillance Center (NCCOSC) providing all technical direction and systems integration functions. Separate development efforts target warehouse interiors and outdoor storage areas. The MDARS Interior effort was initiated in 1989, with the goals of improving the effectiveness of a shrinking security guard force and significantly reducing the intensive manpower requirements associated with accounting for critical and high-dollar assets [Everett, 1995]. The program has successfully demonstrated the ability to control multiple robotic platforms from a single host console with minimal human involvement in a semi-structured warehouse environment. The ability to detect intruders using passive-infrared and microwave motion sensors has been implemented and extensively tested [Smurlo & Everett, 1993]. In 1995, a Broad Agency Announcement (BAA) contract was awarded to Cybermotion, Inc., Salem, VA, to improve the probability of intruder detection, and to integrate the additional capability to perform automated inventory assessment using a platform-mounted interrogator and interactive RF transponder tags attached to warehouse inventory.

The MDARS Exterior effort began in early 1994 with the award of a BAA contract to Robotic Systems Technology, Westminster, MD for the development of two brassboard platforms equipped with autonomous-navigation, collision-avoidance, and intruder-detection capabilities [Myers, 1994; 1995]. A preliminary prototype was successfully demonstrated in October 1994 and several component-level sensor systems have been evaluated off-platform. NCCOSC is expanding the MRHA, initially developed for interior applications, to provide supervisory command and control functions for the exterior robots [Heath-Pastore & Everett, 1994]. The final system will be capable of supporting both interior and exterior platforms to offer site commanders optimal capability and flexibility in an automated security solution.

Intruder detection, assessment and response, product inventories for theft prevention purposes, and lock/barrier checks are some of the physical security and inventory tasks currently performed by government personnel that will be replicated by the exterior robots. Inventory control will consist of verifying the contents of locked structures (i.e., warehouses, bunkers, and igloos) without the need for opening. As is the case for the Interior program, the user's desire for minimum human involvement dictates that the Exterior system operate in a supervised autonomous mode. The Phase I effort will culminate with a technical feasibility demonstration at a government site towards the end of 1997. The follow-up phase will provide enhancements such as intruder detection on the move and a non-lethal response capability.

Multiple Robot Host Architecture

From a technical perspective, the MDARS objective is to field a supervised robotic security system which basically runs itself until an unusual condition is encountered that necessitates human intervention. This requirement implies the MDARS host architecture must be able to respond to exceptional events from several robots simultaneously. Distributed processing allows the problem to be split among multiple resources and facilitates later system expansion through incorporation of additional processors.

The Supervisor computer sits at the top of the hierarchy *(Figure 1)*, responsible for overall system coordination and graphical display of the "big picture," and has at its disposal a number of computing resources, such as one or more Operator Stations, two or more Planner/Dispatchers, a Product Assessment Computer, and a Link Server. The Supervisor and Operator Stations have been similarly configured to provide consistent user-friendly visual displays supporting a point-and-choose menu interface for guard-selectable options and commands. The Operator Station allows a security guard to directly influence the actions of an individual platform with hands-on control of destination, mode of operation, and camera functions. An optional Virtual Reality Display can be connected to the network if desired to provide a realistic three-dimensional model of the operating environment [Everett, et al., 1993].

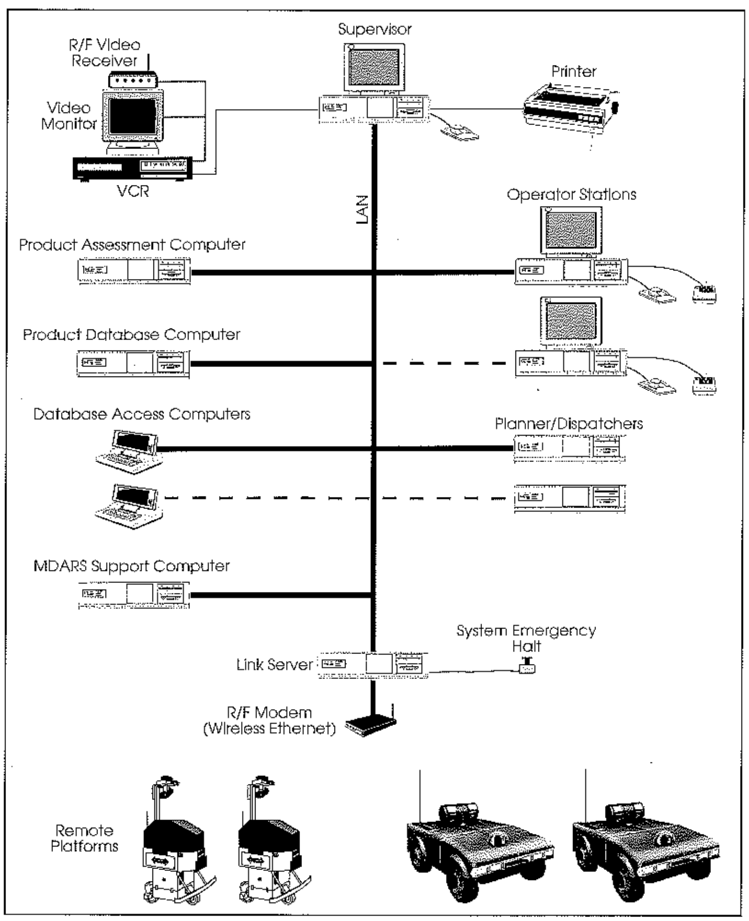

Figure 1. Block diagram of the Multiple Robot Host Architecture developed at NCCOSC for the coordinated control of multiple platforms.

The Planner/Dispatcher computers (an integration of the Cybermotion Dispatcher and the NCCOSC Planner) are responsible for navigation and collision avoidance. The Product Database computer maintains a listing of high-value inventory as verified by an RF tag reading system on board the robot, correlated to geographical location within the warehouse. The Link Server provides an interface to a spread-spectrum RF link between the host and the various robots, and maintains a blackboard data structure of robot status information for immediate retrieval by other computers on the LAN.

A number of "non-deliverable" enhancements have been made to the MRHA to facilitate remote system monitoring and maintenance during final developmental testing prior to installation at the first user site. A computer-controlled video switch has been installed and connected to eight fixed surveillance cameras that cover the entire patrol area of Bay 3 within the Camp Elliott warehouse. The video switch is controlled by software running on the MDARS Support Computer that tracks a designated robot's progress during patrols; as the robot moves into the field of view of a particular camera, the appropriate video signal is automatically selected and routed back to the control van. Two monitors located at the host console are used to observe the robot as it moves through the warehouse, allowing the operator to view both the area the robot is leaving and that into which the robot is moving. These fixed cameras and monitors are used in support of developmental testing only, and are not intended for installation in the final (operational) system.

Video from a steerable camera onboard the robot is also routed on a separate channel back to the control van. Both video channels are input to a Gyyr FasTrans 2000 remote video surveillance system capable of transmitting a single selectable channel to a remote monitoring station over ordinary telephone lines. This remote monitoring feature allows operators or technicians to view live video of an installation site from their home office while performing diagnostic or maintenance activities.

To complement the remote video capability, an "automated attendant" function has been added to the MDARS Support Computer to provide an emergency dial-out capability: if an unrecoverable problem is detected with one of the robots during normal operation, the automated attendant will call a pre-specified telephone number and request assistance. When the call is answered, a brief description of the problem is voiced via speech synthesis, followed by a request for help. With the addition of these two features the system is capable of automatically detecting a fault and calling a repair person to resolve the problem, all without intervention from the normal operator (guard), who may in fact be totally unaware that a problem exists at all. The repair technician thus has the capability to remotely assess the situation using video from either the robot itself or from fixed surveillance cameras monitoring the site.

Interior Platform

The MDARS Interior platform is based on a Cybermotion K2A Navmaster vehicle with MDARS-specific subsystems incorporated. The primary mission of the platform is to patrol a specified area, conducting periodic checks for intruders and reading interactive RF transponder tags affixed to sensitive or high-value inventory items. Current mission modules include an anti-intrusion sensor unit that utilizes both microwave and passive-infrared (PIR) sensors, a controllable video camera to support guard assessment functions, and an RF tag reader for automated inventory assessment. Obstacle detection and avoidance are supported with onboard ultrasonic collision-avoidance sensors, near-infrared proximity detectors, and a safety bumper. Each platform is capable of approximately 12 hours of continuous operation between charges; the recharging process is automatically initiated when battery voltage falls below a specified level.

Development of the MDARS intrusion detection system began in 1989.

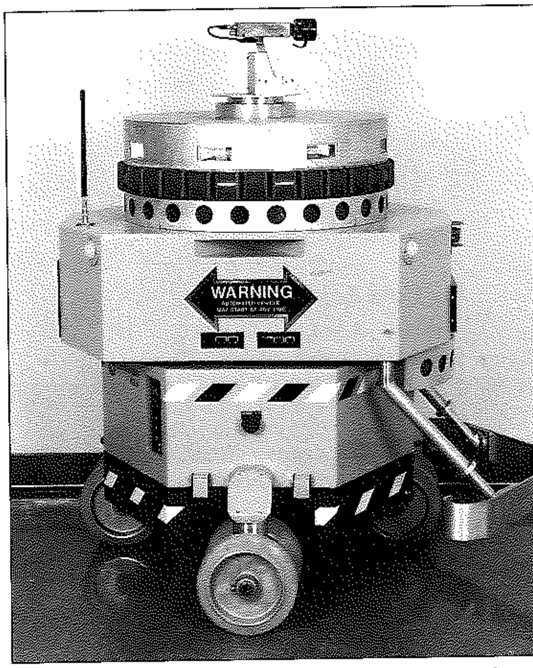

Figure 2. The early MDARS feasibility prototype employed a circular staring array of ultrasonic, microwave, and passive-infrared motion detectors.

As shown in *Figure 2,* the original hardware incorporated multiple sensor arrays, each array consisting of a different type of one or more sensors—passive-infrared, ultrasonic, acoustic, microwave, and video motion detection. With the exception of video, each array contained enough fixed sensors arranged in a circular fashion to cover the entire 360-degree view around the robot. The video motion detector employed a high-resolution zoom camera mounted on a pan-and-tilt unit that was activated only when other sensors detected a possible intruder, at which point the surveillance camera was automatically panned to the appropriate bearing to either confirm or discount a human presence. A sophisticated software algorithm was developed to collect and fuse the information from the many sensors to yield a very high probability of detection while at the same time filtering out all nuisance alarms [Smurlo & Everett, 1993].

The original staring-array security sensor suite was replaced in December 1993 with the more cost-effective Cybermotion Security Patrol Instrumentation (SPI) module shown in *Figure 3* [Holland, 1993]. Developed as an outgrowth of a Cooperative Research and Development Agreement between Cybermotion and NCCOSC, the SPI uses a scanning sensor configuration to achieve the same 360-degree coverage at significantly reduced complexity and cost [DeCorte, 1994]. The SPI Scanner rotates at one revolution per second and contains a vertical array of passive-infrared detectors, a K-Band microwave transceiver, and an optical flame detector [Everett, 1995]. During earlier phases of the MDARS Interior program, this array was extensively tested by the Night Vision and Electronic Sensors Directorate, Ft. Belvoir, VA, and determined to be functionally equivalent to staring sensors that were much more complex.

In October 1993 the MDARS Interior system began extensive test and evaluation in a semi-structured warehouse environment at Camp Elliott in San Diego, CA [Laird, et al., 1993]. A number of technical challenges associated with real-world operation have been uncovered and addressed during this rapid-prototyping test and development phase [Everett, et al., 1994; Gage, et al., 1995]. A significantly upgraded suite of platform hardware will be delivered to the government by Cybermotion at the end of the current BAA contract in 1996 [Holland, et al., 1995]. Formal installation at an actual end-user site is scheduled to occur in the form of Early User Assessment beginning in January 1997.

Exterior Platform

The MDARS Exterior platform weighs approximately 1700 pounds and measures 84 inches long by 35 inches high by 50 inches wide, with an 8-inch ground clearance. The four-wheel hydrostatic-drive configuration is powered by an 18-horsepower three-cylinder diesel engine with a 24-volt alternator and integral power steering pump. An Ackerman-steered design was chosen over a skid-steer arrangement for improved dead-reckoning capability [Everett, 1995]. The water-cooled Kubota engine is directly coupled to a 50cc/rev Rexroth hydrostatic pump that drives four White Industries rotary hydraulic wheel actuators with integral 200-line phase-quadrature encoders. The Rotac hydraulic steering actuator is indepen-

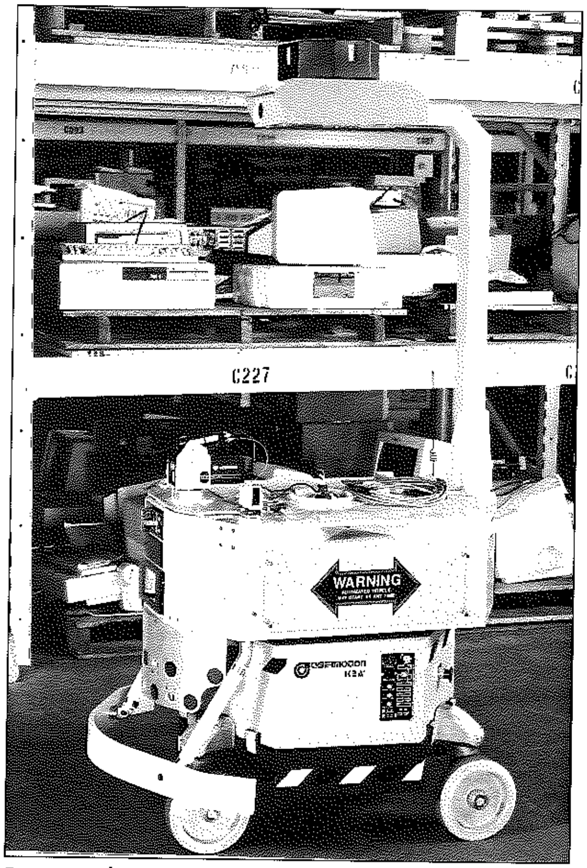

Figure 3. The MDARS Interior robot equipped with the Cybermotion SPI Module on patrol in the Camp Elliott warehouse in San Diego, CA.

dently supplied by the integral power steering pump. The vehicle was carefully designed with an extremely low center of gravity (14.5 inches above ground level) for maximum stability on uneven terrain.

The MDARS Exterior vehicle *(Figure 4)* is required to operate over unimproved roads and fairly rough terrain at speeds up to nine miles per hour, automatically avoiding obstacles greater than six inches, breaches wider than eight inches, and grades steeper than ten percent. The collision avoidance strategy therefore incorporates a two-tier layered approach, wherein long-range, low-resolution sensors provide broad first-alert obstacle-detection coverage, and shorter-range higher-resolution sensors are invoked for more precise obstacle avoidance maneuvering. Candidate systems currently being investigated include: stereo vision [Burt, et al., 1992; 1993], laser ranging [Everett, 1995], millimeter-wave radar [Everett, 1995], and ultrasonic ranging [Hammond, 1994].

The collision avoidance problem for exterior applications is much more

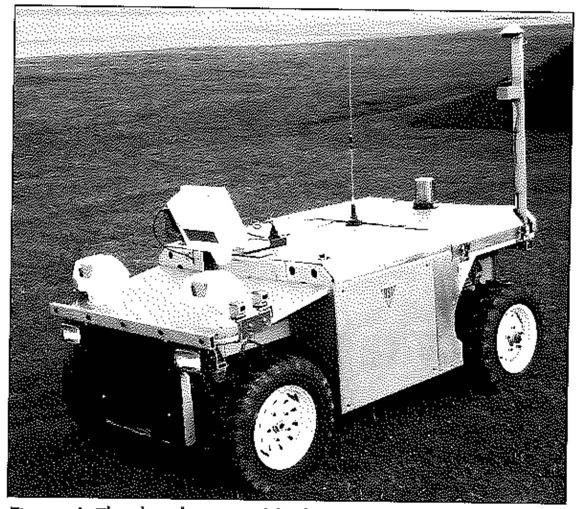

Figure 4. The diesel-powered hydrostatic-drive prototype MDARS Exterior vehicle being demonstrated under pendant control in January 1995.

complex than for interior, even in the case of relatively structured scenarios. For example, the MDARS Exterior vehicle operates almost exclusively on existing facility roadways, for which the associated collision avoidance needs can be subdivided into a number of specific scenarios [Everett, 1995]:

- Fixed obstructions blocking part or all of the roadway.
- Moving obstructions on the roadway.
- Moving obstructions at an intersection (i.e., crossroads or train track).
- Potholes or washouts in the roadway.
- Obstructions along the sides of the roadway.
- Hazards (open ditches, lakes, mud bogs, etc.) along the sides of the roadway.

One of the obvious concerns in fielding an autonomous exterior navigation capability at an industrial site is the need to deal with railroad crossings and roadway intersections. The remote platform must anticipate arrival at such locations in order to "stop and look" before proceeding. The most practical means for detection of oncoming traffic would seem to be Doppler radar and video motion detection.

The added variable which significantly complicates matters in outdoor settings (relative to indoor) is terrain traversability. Wilcox (1994) uses the terminology "non-geometric hazards" to describe pitfalls that cannot be characterized solely by shape, but rather by their properties (such as friction and density that in turn could adversely impact tire slippage or sinkage). In indoor environments, the floor surface is known in advance and is permanent in nature, with the only significant hazards being drop-offs along loading docks and stairwells. Outdoors this is not the case. Road surfaces can undergo day-to-day as well as seasonal variations in drivability, and potentially hazardous conditions can coexist in close proximity along either side. This situation introduces two fundamental problems [Everett, 1995]:

- The potential hazard must be detected in time to suitably alter the vehicle's course.
- Some representation of terrain traversability must be encoded within the world model for consideration by the path planning algorithms.

These issues are of little concern in indoor warehouse environments, where it is generally assumed that any areas of potential danger will be readily detected by onboard sensors before an accident can occur. Even if the remote platform is sufficiently disoriented with respect to its true absolute position and orientation, it is generally physically bounded by some type of structure. If the robot wanders too far from its intended location, it will eventually encounter an easily detectable wall or shelf and be halted by the onboard collision avoidance system.

In outdoor environments, however, there is no such bounding structure. Accumulated dead reckoning errors could result in a large enough offset between actual and perceived platform position and heading to where the vehicle could stray off the roadway. Detection of roadway limits is extremely difficult under all weather conditions likely to be encountered, and there is a very real possibility the platform could wind up in a ditch. The MDARS Exterior vehicle will employ differential GPS for absolute position updates [Grempler, et al., 1995], and localized closed-loop control based on a magnetic lateral position sensing scheme developed by Honeywell and 3M [Stauffer, et al., 1995].

Automatic execution of any avoidance maneuver must also consider the fact that other vehicles may be operating on the road section. It is highly probable that conditions will be encountered where an obstacle blocks all or part of the right side of the road, and the required avoidance maneuver by necessity crosses the roadway centerline. Some reliable means of checking for oncoming traffic must precede any automatic execution of the unrestricted path. As in the case of railroad crossings and roadway intersections above, Doppler radar and image processing are strong contenders for this technological need. It must be realized, however, that humans address this issue with the most sophisticated sensors (eyes) and processing resources (brain) in existence, coupled with an extensive database of learned experiences, yet still on occasion make fatal mistakes.

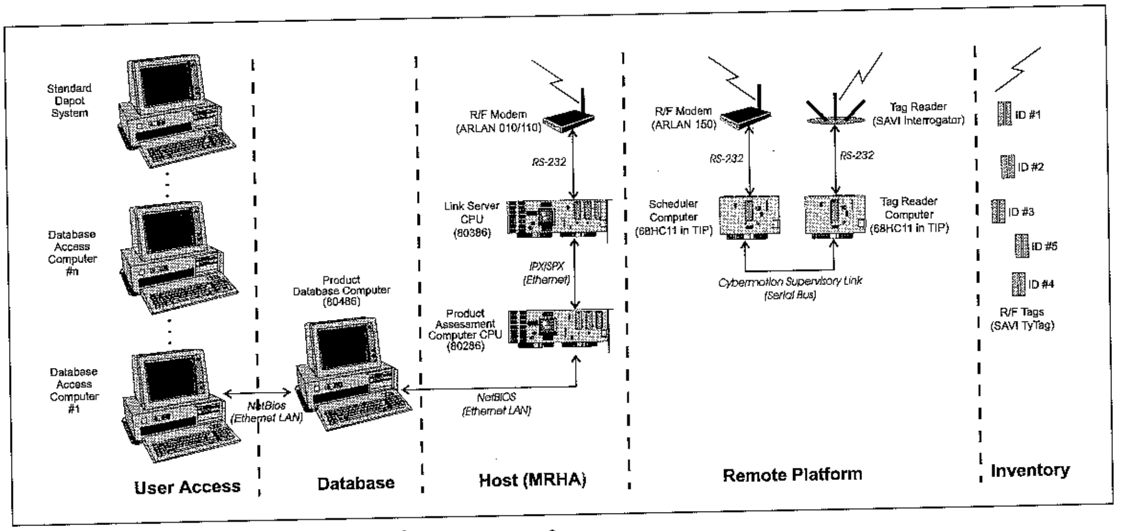

Figure 5. Block diagram of the MDARS Product Assessment System.

Product Assessment System

The purpose of the MDARS Product Assessment System is to provide an interactive means of establishing the actual geographical location of specific items within a warehouse environment for routine comparison to a database of perceived inventory and assigned storage locations [Smurlo, et al., 1995]. The required hardware is physically separated into two groups of components respectively located at the host console and on the robotic platforms as depicted in *Figure 5*. At the host end, the Product Assessment Computer collects tag data from multiple robots, storing the information in the Product Database Computer. The Product Database Computer, as the name implies, is a database that keeps track of all tags read in by the robots as well as those entered manually by the user. The Database Access Computer is the user interface to the Product Database Computer, allowing the entry of manual information, editing of existing tag information, as well as generation and viewing of various tag reports.

The hardware resident on each mobile robot consists of a Savi Technologies Interrogator for bi-directional communication with interactive RF transponder tags attached to high-value or sensitive inventory items [Savi, 1994a] and a controlling Tag Reader Computer. When commanded by a virtual-path program instruction, the Tag Reader Computer collects all tag information from the Interrogator and buffers it in internal blackboard memory for later transfer to the Product Assessment Computer. The Interrogator is an off-the-shelf unit designed for unlicensed operation (below FCC Part 15 power levels) at either 315 or 433.92 Mhz [Lawlor, 1993]. Early models employed three 12-inch stub antennae mounted externally to the semi-spherical housing, 120 degrees apart for full omni-directional coverage, while the most recent version *(Figure 6)* incorporates a pair of antennae inside the housing for a rugged, less-obtrusive profile.

The Interrogator first sends out a wakeup signal consisting of a 3.49-second pulse modulated at 30-Khz, then uploads 10 bytes of data from each responding tag. Savi's proprietary Batch Collection algorithm allows the system to accurately identify thousands of tagged assets at a single read location in a matter of minutes [Savi, 1993]. Individual tags can then be directly addressed for more complex data transfers, such as storing item-unique maintenance or special handling instructions in tag memory for future reference during the product life cycle.

Two types of RF transponder tags are currently used by the MDARS Product Assessment System: the Savi TyTag and the Savi SealTag. Both units are equipped with an onboard piezoelectric beeper that can be activated on command to allow individual tags to be easily located by warehouse personnel [Savi, 1994b]. The TyTag *(Figure 7)* operates on a 6-volt 600-mAh lithium flat-pack battery and will automatically issue a low-battery warning. The minimum operating voltage required to achieve a 25-foot line-of-sight range is 4.16 volts, and typical battery life is two years with two data collections per day. TyTags are normally intended for indoor operation only and are available with 128 or 256 bytes of non-volatile memory.

The SealTag *(Figure 7)* is enclosed in a rugged environmental package suitable for exposed outdoor operation and is available with an extended non-volatile memory of up to 128 kilobytes for mass storage of information such as product history or container manifests [Savi, 1994b]. A 6-

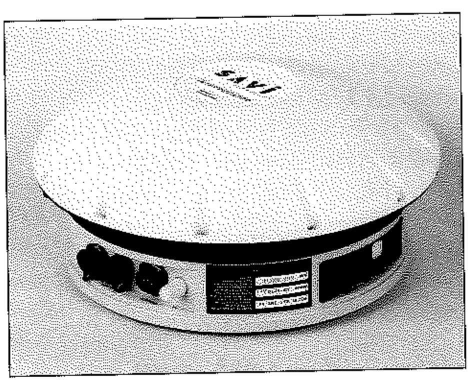

Figure 6. The Savi Interrogator is a microprocessor-controlled RF transceiver capable of omnidirectional read/write operations to transponder tags located up to 150 feet away.

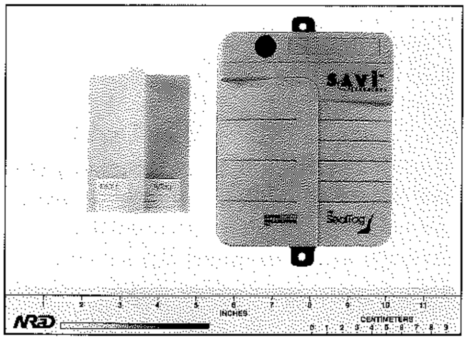

Figure 7. The Savi TyTag (left) is an interactive RF transponder with up to 256 bytes of read/write memory storage; the SealTag (right) can have up to 128 kilobytes and is equipped with four binary

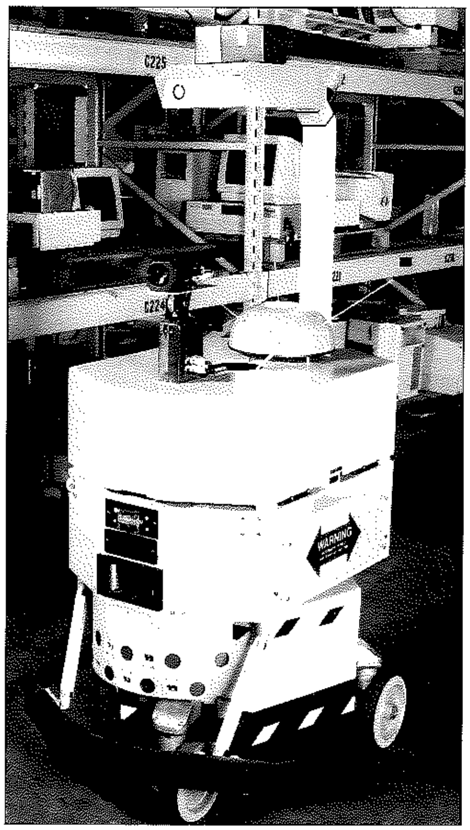

Figure 8. An earlier model of the Savi Interrogator mounted on top of the MDARS Interior robot undergoing feasibility testing at the Camp Elliott warehouse facility in San Diego, CA.

volt 1400-Mah lithium battery provides an expected service life of four years assuming two data collections per day, and battery status is automatically monitored as well. A real-time clock is incorporated into the SealTag design to facilitate time-stamping data or event occurrences.

An inverted-TTL RS-232 serial interface and four binary I/O lines are provided on the SealTag to communicate with auxiliary equipment and/or monitor external events. A change in logic level of an input line will toggle the state of an associated bit in the data stream read by the Interrogator, greatly expanding the versatility of the system. For example, an input line on a SealTag will be used in the MDARS Exterior program to monitor the physical status (open or shut) of high-security locks and will upload this information along with the lock serial number to the patrolling MDARS vehicle upon request. In this fashion, the same hardware used to verify inventory inside a locked space can also be used to collect information describing related conditions (i.e., flooding, fire, smoke).

In January 1995, extensive testing was conducted by the MDARS development team at the Camp Elliott warehouse facility in San Diego *(Figure 8)* to assess the accuracy of several tag-position-estimation algorithms [Smurlo, et al., 1995]. The test was also designed to determine the impact of performing tag-read operations at two different stop intervals (37.5 and 75 feet) along the route, using 173 Savi TyTags placed at known locations throughout the warehouse. For survey intervals of 37.5 feet, the best performing algorithm achieved an average of approximately 15 feet positional uncertainty (the difference between estimated and actual tag locations), while for survey intervals of 75 feet the uncertainty was increased to approximately 20 feet [Smurlo, et al., 1995]. US

References

DeCorte, C. "Robots Train for Security Surveillance," **Access Control,** June 1994, pp. 37-38.

Everett, H.R., Gilbreath, G.A., Heath-Pastore, T.A., Laird, R.T. "Coordinated Control of Multiple Security Robots," **SPIE Mobile Robots VIII,** Boston, MA, September 1993.

Everett, H.R., Gage, D.W., Gilbreath, G.A., Laird, R.T., Smurlo, R.P. "Real-World Issues in Warehouse Navigation," **SPIE Mobile Robots IX,** Boston, MA, 2-4 November 1994, SPIE vol. 2352.

Everett, H.R. **Sensors for Mobile Robots: Theory and Application,** ISBN 1-56881-048-2, AK Peters, Ltd., Wellesley, MA, 1995.

Gage, D.W., Everett, H.R., Laird, R.T., Heath-Pastore, T.A. "Navigating Multiple Robots in Semi-Structured Environments," **ANS 6th Topical Meeting on Robotics and Remote Systems,** American Nuclear Society, Monterey, CA, February 1995.

Grempler, C., Kurtz, J., Litwin, L. "MDARS Exterior GPS Survey," **Proceedings of AUVS '95,** Washington, DC, 10-12 July 1995.

Heath-Pastore, T.A., Everett, H.R. "Coordinated Control of Interior and Exterior Autonomous Platforms," **ISRAM '94, Fifth International Symposium on Robotics and Manufacturing,** Maui, HI, August 1994.

Holland, J.M. "An Army of Robots Roams the Night," **International Robot and Vision Automation Show and Conference,** Detroit, MI, April 1993, pp. 17.1-17.12.

Holland, J.M., Martin, A., Smurlo, R.P., Everett, H.R. "The MDARS Interior Platform," **Proceedings of AUVS '95,** Washington, DC, 10-12 July 1995.

Laird, R.T., Everett, H.R., Gilbreath, G.A. "A Host Architecture for Multiple Robot Control," **ANS Fifth Topical Meeting on Robotics and Remote Handling,** Knoxville, TN, April 1993.

Lawlor, M. "Microcircuit Technology Improves Readiness, Saves Resources," **Signal,** Armed Forces Communications and Electronics Association, August 1993.

Myers, S.D. "Design of an Autonomous Exterior Security Robot," **NASA Conference Publication 3251,** vol. 1, Conference on Intelligent Robotics in Field, Factory, Service, and Space, Houston, TX, March 1994, pp. 82-87.

Myers, S.D. "The MDARS Exterior Platform," **Proceedings of AUVS '95,** Washington, DC, 10-12 July 1995.

Savi. "The Savi Asset Management System," **Product Brochure,** Savi Technology, Inc., Mountain View, CA, 1993.

Savi. "System Components," **Product Literature,** Savi Technology, Inc., Mountain View, CA, April 1994a.

Savi. "Savi Technology Ordering Guide," **First Edition, Radio Frequency Identification Equipment Contract No. F33600-94-D-0077,** Savi Technology, Inc., Mountain View, CA, November 1994b.

Smurlo, R.P., Everett, H.R. "Intelligent Sensor Fusion for a Mobile Security Robot," **Sensors,** June 1993, pp. 18-28.

Smurlo, R.P., Laird, R.T., Everett, H.R., Inderieden, R.S., Elaine, S., Jaffee, D.M. "MDARS Product Assessment System," **Proceedings of AUVS '95,** Washington, DC, 10-12 July 1995.

Stauffer, D., Lenz, J., Dahlin, T.J. "A Magnetic Lateral Guidance Concept Using Continuous Magnetic Marking," submitted for publication to **IEEE Control Systems Journal,** 1995.

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these industries (e.g., American Nuclear Society Topical Meetings on Robotics and Remote Systems).

In addition to written materials, an increasing amount of information on robotics is becoming available on the Internet, the most user-friendly access method being the World Wide Web. For an introduction to the Web, see [Gage, 1994], or consult your local computer guru. Useful Web starting points include the Robotics Internet Resources Page [URL-Robotics] at the University of Massachusetts and the Computer Vision Home Page [URL Vision] at Carnegie Mellon. These focus principally on university research groups and projects that serve information on the Internet, while the comp.robotics Frequently Asked Questions [URL - FAQ] provides pointers to more diverse robotics resources such as robot clubs and societies around the world, magazines of interest, and component manufacturers. Non-academic UV efforts are not yet well-represented on the Internet. The ARPA UGV Demo II Project is in evidence through the CMU's NavLab Web pages [URL-NavLab] and University of Michigan's UGV pages [URL - UMich/UGV]. Martin-Marietta makes Demo II project data available to approved users (associated project participants) through an anonymous ftp server. Also, try out the "under construction" AUVSI Homepage [URL- AUVS], and look for a new DTIC-sponsored UV database coming from AUVSI later this year [Thurman, 1995]. US

References

[Asker, 1994] Asker, J.R. "NASA's Dante 2 Advances Robotics," **Aviation Week and Space Technology**, vol. 41, 15 August 1994, p 23.

[Aviles, 1990] Aviles, W.A., et al. "Issues in Mobile Robotics: The Unmanned Ground Vehicle Program TeleOperated Vehicle (TOV)," **Proceedings of SPIE Mobile Robots V**, Boston, MA, 8-9 November 1990, SPIE vol. 1388, pp 587-597.

[Bishop, 1994] Bishop, J.R. "Status of the Automated Highway System Program," **Proceedings of AUVS-94**, Detroit, MI, 23-25 May 1994, pp 59-62.

[Burke, 1995] Burke, J.D., et al, "Field Test of a Russian Rover in the California Desert," **Proceedings of the ANS 6th Topical Meeting on Robotics and Remote Systems**, Monterey, CA, 5-10 February 1995, pp 425-432.

[Byrne, 1992] Byrne, R.H., and Klarer, P.R. "Military Robotics Technologies," **Unmanned Systems**, Spring 1992, vol. 10, no. 2, pp 42-47.

[Chun, 1994] Chun, W.H., and Jochem, T.M. "Unmanned Ground Vehicle Demo II: Demonstration A," **Proceedings of SPIE Mobile Robots IX**, Boston, MA, 2-4 November 1994, SPIE vol. 2352, pp 180-191.

[DARPA, 1986] Defense Advanced Research Projects Agency, **Strategic Computing Program Second Annual Report**, Arlington, VA, February 1986.

[Davies, 1990] Davies, H.C., Kayaalp, A.E., and Moezzi, S. "Autonomous Navigation in a Dynamic Environment," **Proceedings of AUVS-90**, Dayton, OH, 30 July - 1 August 1990, pp 318-335.

[Desai, 1992] Desai, R.S., Wilcox, B.H., and Bedard, R.J. "Jet Propulsion Laboratory Robotic Vehicle Overview," **Unmanned Systems**, Summer 1992, vol. 10, no. 3, pp 16-21.

[Douglass, 1988] Douglass, Robert J. "The DARPA Autonomous Land Vehicle: a Phase I Retrospective and a Prospective for the Future," **Proceedings of the Conference on Space and Military Applications of Automation and Robotics**, Huntsville, AL, 21-22 June 1988, p 249.

[Everett, 1982] Everett, H.R. "A Microprocessor Controlled Autonomous Sentry Root," Masters thesis, Naval Postgraduate School, Monterey, CA, October 1982.

[Everett, 1988] Everett, H.R. "Security and Sentry Robots," **International Encyclopedia of Robotics: Applications and Automation**, Wiley and Sons, NY, 1988, pp 1462-1476.

[Everett, 1990] Everett, H.R., G.A. Gilbreath, T. Tran, J.M. Nieusma, **Modeling the Environment of a Mobile Security Robot**, TD 1835, Naval Ocean Systems Center, San Diego, CA, June 1990.

[Everett, 1995] H.R. Everett. **Sensors for Mobile Robots: Theory and Application**, ISBN 1-56881-048-2, AK Peters, Ltd., Wellesley, MA, 1995.

[Flynn, 1985] Flynn, A.M. "Redundant Sensors for Mobile Robot Navigation," MIT AI Lab Technical Report 859, 1985.

[Gage, 1994] Gage, D.W. "Internet Tools for Sharing Unmanned Vehicle Information," **Proceedings of AUVS-94**, Detroit, MI, 23-25 May 1994, pp 563-570.

[Gage, 1995] Gage, D.W., Everett, H.R., Laird, R.T., and Heath-Pastore, T.A. "Navigating Multiple Robots in Semi-Structured Environments," **Proceedings of the ANS 6th Topical Meeting on Robotics and Remote Systems**, Monterey, CA, 5-10 February 1995, pp 838-845.

[Giralt, 1983] Giralt, G., Chatila, R. and Vaisset, M. "An Integrated Navigation and Motion Control System for Autonomous Multisensory Mobile Robots," **Proceedings of the First International Symposium of Robotics Research**, 1983.

[Gothard, 1992] Gothard, B., Spomer, R.L., Medina, J., and Chun, W. "Design Issues with the SSV Platform," **Proceedings of SPIE Mobile Robots VII**, Boston, MA, 18-20 November 1992, SPIE vol. 1831, pp 320-331.

[Hall, 1992] Hall, J. "Unmanned Ground Vehicle — An Update," **Unmanned Systems**, Spring 1992, vol. 10, no. 2, pp 16-19.

[Harmon, 1986] Harmon, S.Y. "Autonomous Vehicles," **Encyclopedia of Artificial Intelligence**, Wiley and Sons, NY, 1986, pp 39-45.

[Harmon, 1987] Harmon, S.Y. "The Ground Surveillance Robot (GSR): An Autonomous Vehicle Designed to Transit Unknown Terrain," **IEEE Journal of Robotics and Automation**, vol. RA-3, no. 3, June 1987, pp 266-279.

[Hightower, 1986] Hightower, J.D., Smith, D.C., and Wiker, S.F. "Development of Remote Presence Technology for Teleoperator Systems," **Proceedings of the 14th Meeting of the UJNR/MFP**, September 1986.

[Kemurdjian, 1995] Kemurdjian, A.L., and Potemkin, E.K. "Mobility of Planetary Vehicles: Problems and Reality," **Proceedings of the ANS 6th Topical Meeting on Robotics and Remote Systems**, Monterey, CA, 5-10 February 1995, pp 433-442.

[Klafter, 1988] Klafter, R.D. "Mobile Robots, Research and Development," **International Encyclopedia of Robotics: Applications and Automation**, Wiley and Sons, NY, 1988, pp 920-943.

[Martin Marietta, 1986] Martin Marietta Denver Aerospace, **The Autonomous Land Vehicle Program**, handout at June 1986 ALV demonstration, Denver, CO.

[Maurer, 1994] Maurer, M., et al. "VaMoRs-P - An Advanced Platform for Visual Autonomous Road Vehicle Guidance," **Proceedings of SPIE Mobile Robots IX**, Boston, MA, 2-4 November 1994, SPIE vol. 2352, pp 239-248.

[McGhee, 1985] McGhee, R.B. and Waldron, K.J. "The Adaptive Suspension Vehicle Project: A Case Study in the Development of an Advanced Concept for Land Locomotion," **Unmanned Systems**, Summer 1985, vol. 4, no. 1, pp 34-43.

[Metz, 1992] Metz, C.D., Everett, H.R., and Myers, S. "Recent Developments in Tactical Unmanned Ground Vehicles, **Proceedings of AUVS-92**, Huntsville, AL, 22-24 June 1992.

[Meystel, 1991] Meystel, A. **Autonomous Mobile Robots — Vehicles with Cognitive Control**, World Scientific Publishing Co, Singapore, 1991, chapter 2.

[Moravec, 1983] Moravec, H.P. **The Stanford Cart and CMU Rover**. Technical Report, Robotics Institute, Carnegie-Mellon University, February 1983.

[Moravec, 1985] Moravec, H.P. and Elfes, A. "High Resolution Maps from Wide Angle Sonar," **Proceedings of 1985 IEEE International Conference on Robotics and Automation**, St. Louis MO, 25-28 March 1985, pp 116-121.

[Murphy, 1995] Murphy, D.W. and Bott, J.P. "The Air-Mobile Ground Security Surveillance System (AMGSSS)," **Unmanned Systems**, Summer 1995, vol. 13, no. 3 (this issue).

[Nilsson, 1969] Nilsson, N.J. "A Mobile Automaton: An Application of Artificial Intelligence Techniques," **Proceedings of the First International Joint Conference on Artificial Intelligence**, Washington, DC, May 1969, pp 509-520.

[Mobile Robots III, 1988] **Proceedings of SPIE Mobile Robots III**, Cambridge MA, 10-11 November 1988, SPIE vol. 1007, pp 72-145.

[Mobile Robots IV, 1989] **Proceedings of SPIE Mobile Robots IV**, Philadelphia PA, 6-7 November 1989, SPIE vol. 1195, pp 98-179.

[Rajaram, 1988] Rajaram, N.S. "Automated Guided Vehicle Systems," **International Encyclopedia of Robotics: Applications and Automation**, Wiley and Sons, NY, 1988, pp 130-136.

[Sharma, 1987] Sharma, U.K. and McTamaney, L.S. "Real Time System Architecture for a Mobile Robot," **Proceedings of SPIE Mobile Robots II**, Cambridge, MA, 5-6 November 1987, SPIE vol. 852, pp 25-31.

[Shimamoto, 1992] Shimamoto, M.S. "TeleOperator/telePresence System (TOPS) Concept Verification Model (CVM) Development," in **Recent Advances in Marine Science and Technology, '92**, Saxena, N.K., ed., Pacon International, Honolulu, HI, pp 97-104.

[Thorpe, 1990] Thorpe, C.E., ed. **Vision and Navigation: The Carnegie Mellon Navlab**, Kluwer, Boston, MA, 1990.

[Thurman, 1995] Thurman, K.R. "The Road Warrior: News from the Information Superhighway," **Unmanned Systems**, Winter 1995, vol. 13, no. 1, p 36.

[Toscano, 1992] Toscano, M. "Department of Defense Ground Vehicle Robotics Program," **Unmanned Systems**, Spring 1992, volume 10, number 2, pp 14-15.

[UGV/S-JPO, 1995] UGV/S-JPO. "Tactical Unmanned Ground Vehicle Program," **Unmanned Systems**, Winter 1995, vol. 13, no. 1, pp 23-30.

[URL - AUVS] http://asrt.cad.gatech.edu/AUVS/

[URL - FAQ] http://www.frc.ri.cmu.edu/robotics-faq/

[URL - Robotics] http://piglet.cs.umass.edu:4321/robotics.html

[URL - NavLab] http://www.cs.cmu.edu:8001/afs/cs.cmu.edu/project/alv/member/www/navlab_home_page.html

[URL - Umich/UGV] http://ai.eecs.umich.edu/ugv/home-page.html

[URL - Vision] http://www.cs.cmu.edu/cil/vision.html

[Vuk, 1984] Vuk, M.M. and Lee, W.T. "A Mobile Military Security System: Tactical Application of the PROWLER Robot," **Unmanned Systems**, Spring 1984, vol. 2, no. 4, pp 28-31.

[Weiss, 1988] Weiss, J.A. and Simmons, R.K. "TMAP - a Versatile Mobile Robot," **Proceedings of SPIE Mobile Robots III**, Cambridge MA, 10-11 November 1988, SPIE vol. 1007, pp 298-308.

[Wilcox, 1988] Wilcox, B.H., and Gennery, D.B. "A Mars Rover for the 1990s," **Journal of the British Interplanetary Society**, vol. 40, pp 484-488, 1987. Reprinted in **Proceedings of AUVS-88**, San Diego CA, 6-8 June 1988.

[Young, 1990] Young, S. "Military Explores Robotic Technology to Keep Soldiers from Harm's Way," **Unmanned Systems**, Fall 1990, vol. 8, no. 4, pp 39-42.